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Research Paper

Dung beetle dominance shapes functional structure in a Central African urban forest in RD Congo.

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Abstract
Tropical forests are vital for biodiversity and ecosystem services, yet studies of functional diversity in soil-surface beetles in Central African urban forests remain scarce. We assessed epigeic beetle communities in the Kisangani Botanical and Zoological Garden, DR Congo, using pitfall traps over six weeks and analyzed taxonomic and functional diversity based on traits such as diet and dispersal. Results showed a community dominated by the coprophagous Scarabaeidae genera Digitonthophagus and Onthophagus, which together comprised 80% of individuals, indicating that dung-associated resources likely contribute to structuring the beetle assemblage and may create conditions consistent with a resource-island effect. Temporal patterns revealed fluctuations in abundance and diversity linked to environmental conditions. These findings suggest urban forest fragments can sustain specialized beetle-mediated ecosystem functions, though with limited functional diversity. Trait-based assessments provide valuable insights for urban biodiversity conservation and ecosystem management in tropical forest landscapes.

Keywords:*Tropical Forests; Epigeic Beetles; Functional Diversity; Urban Ecology; Biodiversity Conservation*

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I. Introduction

Tropical forests are among the world's most critical biomes, playing a vital role in biodiversity conservation and the provision of ecosystem services (Borma*et al.*, 2022). Despite the exceptional biodiversity and rapid urbanization pressures in Central Africa, studies on the functional diversity of epigeic beetles in this region remain limited (Langraf, Gajdoš, *et al.*, 2024; Langraf, Petrovičová, *et al.*, 2024). Coleoptera, one of the most diverse and abundant insect orders, occupies a wide range of ecological niches and plays a major role in terrestrial ecosystem functioning (He *et al.*, 2024). Epigeic beetles, which inhabit the soil surface or litter layer, contribute to key processes such as organic matter decomposition, invertebrate population regulation, and soil structuring (Langraf *et al.*, 2024). Due to their sensitivity to environmental disturbances, epigeic beetles are effective bioindicators of habitat ecological quality (Ghannèm*et al.*, 2017).

Global interest in trait-based and functional approaches to biodiversity has intensified, as species richness alone inadequately quantifies the effects of biodiversity loss on ecosystem processes, resilience, and service delivery in human-modified landscapes (Jaeger *et al.*, 2022). This is especially relevant in tropical cities, where remnant forests, botanical gardens, zoological parks, and other green enclaves increasingly function as micro-refugia within expanding urban matrices. These habitats are now recognized not only as local conservation spaces but also as strategic observatories for testing broader ecological questions related to biotic homogenization, environmental filtering, ecosystem engineering, and the persistence of ecological functions under urban stress.

Urban forests serve as essential biodiversity refuges, yet urban expansion and anthropogenic activities drive accelerated habitat fragmentation and expose these forests to pressures such as trampling, pollution, deadwood collection, and deforestation, which alter natural microclimates (Kotze *et al.,* 2022). Such disturbances can lead to shifts in functional diversity, including reductions in functional richness and ecological resilience in disturbed habitats. These changes may compromise important ecosystem functions such as organic matter decomposition, nutrient cycling, and soil regeneration (Cadotte *et al*., 2011; Nichols *et al*., 2008; deCastro‐ Arrazola *et al*., 2022).

In the Democratic Republic of the Congo, forest ecosystems are progressively degraded by deforestation, urbanization, and landscape fragmentation (Shapiro *et al*., 2016, 2021). In Kisangani, the Kisangani Botanical and Zoological Garden (KBZG) represents a critical urban forest island (Balandi*et al.,* 2024). However, anthropogenic pressures have demonstrably impacted the soil community structure at this site. Studying the functional diversity of epigeic insects within the KBZG forest facilitates ecosystem health assessment and informs urban conservation actions.

Placing the KBZG study in context is important, as tropical African cities are underrepresented in urban ecology literature (Awoyemi & Ibáñez‐ Álamo, 2023), despite experiencing rapid demographic growth and land-use change (Cavan *et al*., 2014). Consequently, studies from Central Africa can contribute substantially to comparative urban biodiversity science by documenting whether the ecological patterns described in Latin America (Piano *et al*., 2020) or temperate cities also occur in Congo Basin forest fragments. Thus, the present study has value beyond Kisangani, as it helps fill a major geographic gap in the evidence on how urbanization reshapes invertebrate-mediated ecosystem functions in tropical forests.

Interest in functional diversity has increased in recent decades, as it surpasses simple taxonomic richness by clarifying the mechanisms linking biodiversity to ecosystem functioning (Mammola *et al*., 2021). Functional and taxonomic diversity are increasingly considered complementary tools for assessing biodiversity responses to environmental disturbance and land-use change (Joimel et al., 2021). Functional diversity quantifies the variety of biological and ecological traits, which influence organism performance and contributions to ecosystem processes (Lefcheck*et al*., 2014). Traits of epigeic beetles—such as body size, trophic guild, dispersal capacity, and habitat affinity—dictate their roles in decomposition, soil structuring, and trophic web stability (Pey *et al.,* 2014). Therefore, a detailed assessment of epigeic beetles in KBZG is essential for enhancing understanding of urban biodiversity, evaluating forest soil resilience, and informing conservation and ecological restoration efforts in the Kisangani region.

Botanical and zoological gardens within urban matrices function as ecological refugia, sustaining favorable microclimatic conditions despite significant urban transformation (Gentili *et al*., 2023; Odri *et al*., 2025). To address the knowledge gap, we formulated two hypotheses. First, under the Resource Island hypothesis, we predict that the continuous availability of animal excreta within the zoological garden will favor coprophagous Scarabaeidae and lead to a strong functional dominance of dung-associated beetles relative to other trophic guilds. This pattern is expected to be reflected by the predominance of genera such as *Digitonthophagus* and *Onthophagus*within the beetle assemblage. Such specialization would identify gardens as functional refuges where specific ecosystem engineers maintain essential nutrient cycling services despite the surrounding urban matrix (Asha *et al*., 2022; Nichols *et al*., 2008).

Secondly, because tropical insect activity is highly responsive to short-term environmental variation, we anticipate that functional diversity patterns may be more sensitive than simple taxonomic richness to temporal changes occurring during the sampling period (Dijk et al., 2024).Specifically, we expect that the functional identity and trait distribution of the epigeic beetle community will shift in response to transitions between dry and rainy spells in the Congo Basin, revealing how the urban forest fragment buffers or intensifies environmental stressors for different beetle guilds (Dijk *et al*., 2024).

In this study, we assessed and compared the functional diversity of epigeic beetles within the Kisangani Botanical and Zoological Garden(KBZG) forest. Our objectives were to (i) characterize the functional composition of the epigeic beetle community, (ii) analyze differences in functional richness and structure associated with habitat, and (iii) discuss the implications for urban forest biodiversity conservation. This functional approach provides a deeper understanding of how these organisms adapt to anthropogenic pressures and contribute to ecosystem services in fragmented urban landscapes (Correa *et al*., 2023; Mbora, 2022).

By serving as a case study within a tropical-urban framework, this research contributes to international efforts to develop scalable biodiversity indicators for cities and fragmented forest landscapes. Epigeic beetles respond rapidly to changes in resource availability, litter structure, soil conditions, and disturbance intensity, making them valuable for standardized monitoring across regions (Ghannèm*et al.*, 2017; Lawes *et al*., 2005). Evidence generated from Kisangani informs site-level management and broader discussions on urban forest restoration, green-space design, and biodiversity-sensitive planning in tropical regions worldwide.

II. Materials and Methods

Study area

The Kisangani Botanical and Zoological Garden (0°36'N, 25°13'E) is located 5 km from the city of Kisangani, in the northeast, along the Buta road, in the Tshopo commune (Tshopo Province, DR Congo). It covers 120 ha, including 84 ha of the zoological garden and 40 ha corresponding to the Tshopo River loop. It is a property of the Ministry of Environment and Sustainable Development (MEDD), created by ordinance-law n° 78-215 du 5 mai 1978 (Republique du Zaïre, 1978), and managed by the Congolese Institute for Nature Conservation (ICCN). The river loop protects the Tshopo dam. This dam supplies the city with electricity. Figure 1 illustrates the KBZG location.

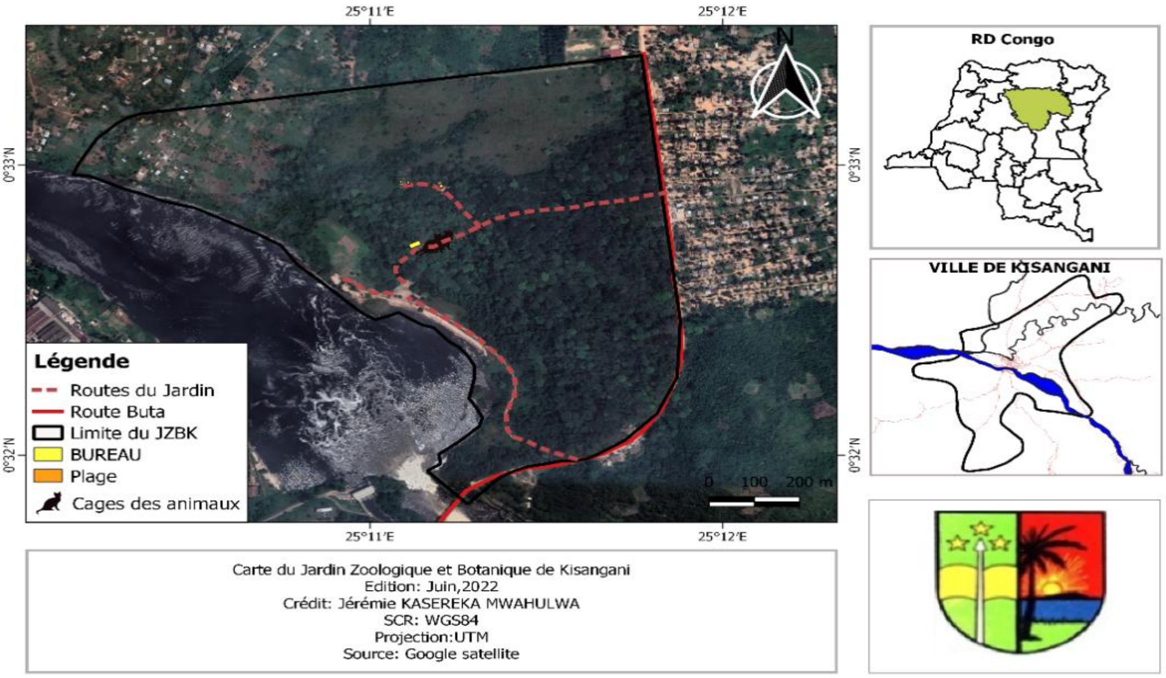

Figure 1. Geographic location of the Kisangani Botanical and Zoological Garden (KBZG), Kisangani, Tshopo Province, Democratic Republic of the Congo. The map shows the study area where epigeic beetles were sampled.

Sampling of epigeic beetles

We installed 60 non-baited Barber pitfall traps in three lines, 50 m apart. Non-baited traps were deliberately selected to characterize the broader epigeic beetle assemblage rather than specifically target dung beetles. This approach allowed the assessment of naturally occurring activity-density patterns without introducing an artificial attractant that could bias community composition toward coprophagous taxa.Theseare collected ground-dwelling insects from the litter. We checked traps every 3 days for 6 weeks. Collected beetles were preserved in 70% ethanol, sorted, and identified to the genus level using regional and international taxonomic keys (e.g., Birkhofer *et al*., 2011; Magurran, 2004).

Statistical analyses

We conducted statistical analyses in R (v4.5.1) using vegan.(Oksanen et al., 2001), FD (Laliberté & Legendre, 2010), and ggplot2 (Wickham, 2016) packages. We organized data into two matrices: (1) beetle abundances per sampling unit, and (2) functional traits (body size, diet, activity, dispersal capacity, etc.).

We calculated species (genus-level) richness and taxonomic diversity indices (Shannon, Simpson) to characterize community structure. We also computed functional diversity indices: FRic (Functional Richness), FEve (Functional Evenness), and FDis (Functional Dispersion).

We assessed diversity differences among microhabitats or disturbance levels using analysis of variance (ANOVA) or Kruskal–Wallis tests, depending on assumption adherence. We evaluated normality (Shapiro–Wilk test) and homogeneity of variances (Levene's test). Post hoc tests (Tukey or Dunn) facilitated pairwise comparisons. We explored functional community composition using non-metric multidimensional scaling (NMDS) based on Bray–Curtis dissimilarity. The NMDS ordination yielded a stress value of 0.251. We further analyzed community composition using Principal Coordinates Analysis (PCoA) based on Bray–Curtis dissimilarity. This method effectively quantifies community composition differences, independent of shared absences(Field *et al*., 1982). We square-root transformed abundance data to reduce the influence of highly abundant taxa while retaining relative differences among samples, an approach commonly used with Bray–

Curtis dissimilarities for community composition analyses. Ordination was then performed using a Bray–Curtis dissimilarity matrix derived from the transformed abundances.
The dataset did not contain explicit unique trap identifiers. Repeated sampling units were reconstructed from sample labels using site, sampling date, and trap-position information. Each unique combination was treated as an independent sampling unit, and the dataset was manually checked to avoid duplicate records and maintain statistical independence.This process generated a community matrix (65 samples, 21 genera). We utilized ordination scores from the first two principal coordinate axes to visualize compositional variation patterns among sampling dates. We calculated the proportion of variation explained by each axis from its positive eigenvalues.

III. Results

1. Overall composition of the beetle assemblage
We collected 198 epigeic beetle individuals, representing 12 genera distributed across 10 families (Table 1). Scarabaeidae strongly dominated the assemblage, specifically through the coprophagous genera *Digitonthophagus* and *Onthophagus*(Jácome-Hernández *et al.*, 2023). Together, these genera comprised a major proportion of sampled individuals, clearly demonstrating a highly uneven community structure. Other genera, including *Maladera, Tenebrio, Trachys, Calathus, Dermestes, Harpalus, Lampyris, Sitophilus, Brassicogethes,* and*Strophosoma* exhibited significantly lower abundances.

Table 1. Taxonomic composition, total abundance, and relative contribution of epigeic beetle genera recorded in the study area

Family	Genus	Total abundance (n)	Contribution to total abundance (%)
Buprestidae	*Trachys*	11	5.6
Carabidae	*Calathus*	7	3.5
Carabidae	*Harpalus*	1	0.5
Curculionidae	*Stohoposoma*	1	0.5
Dermestidae	*Dermestes*	4	2
Dryophthoridae	*Sitophilus*	4	2
Lampyridae	*Lampyris*	1	0.5
Melolonthidae	*Maladera*	4	2
Nitidulidae	*Brassicogethes*	1	0.5
Scarabaeidae	*Digitonthophagus*	111	56.1
Scarabaeidae	*Onthophagus*	48	24.2
Tenebrionidae	*Tenebrio*	5	2.5
Total		198	100

2. Functional composition of beetle abundance
The beetle assemblage exhibited a highly uneven functional composition, with the coprophagous guild clearly dominating and comprising 159 individuals (80% of total abundance). In contrast, other guilds were represented by much lower numbers: phytophagous leaf-miner/wood-borers (11 individuals), predatory ground beetles (7), detritivorous beetles (5), and granivorous, necrophagous, and phytophagous root-and-leaf feeders (4 each). Omnivorous, pollen-feeding, phytophagous stem/seed feeders, and predatory snail-feeding larvae were each represented by a single individual. This pattern demonstrates the functional dominance of dung-associated beetles within the assemblage.

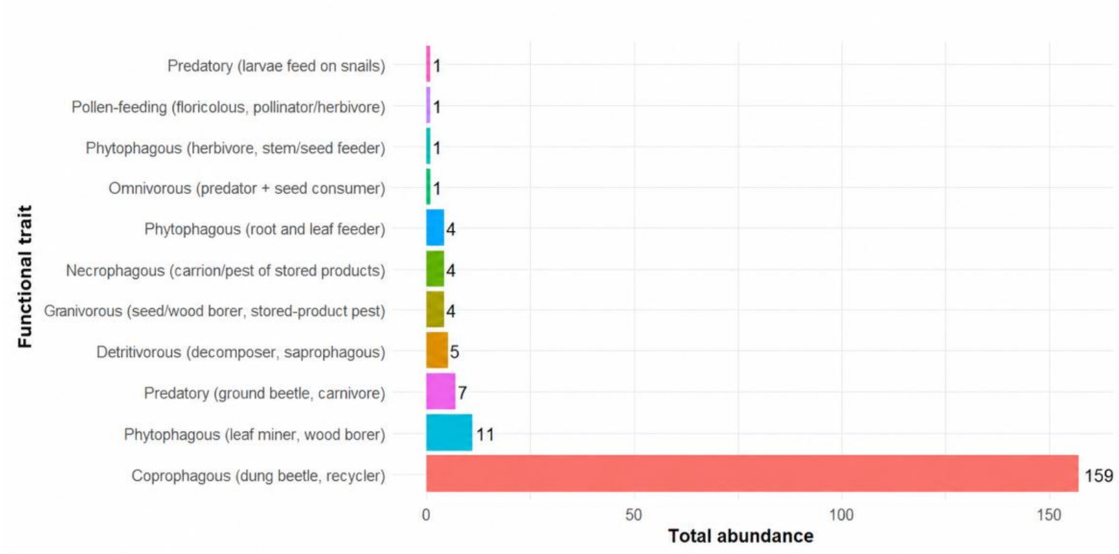

Figure 2.Functional composition of epigeic beetles recorded in the Kisangani Botanical and Zoological Garden. Bars represent the total abundance of individuals within each functional group.

3. Genus accumulation curve and sampling adequacy

The genus accumulation curve increased rapidly during the initial sampling units and progressively approached an asymptote. Although the rate of accumulation declined after approximately the eighth sample, the curve continued to increase slightly throughout the survey, suggesting that most common genera were captured while additional sampling could still reveal rare taxa (Figure 3). However, the slight upward trend at the end of the curve suggests that additional sampling could reveal rare genera.

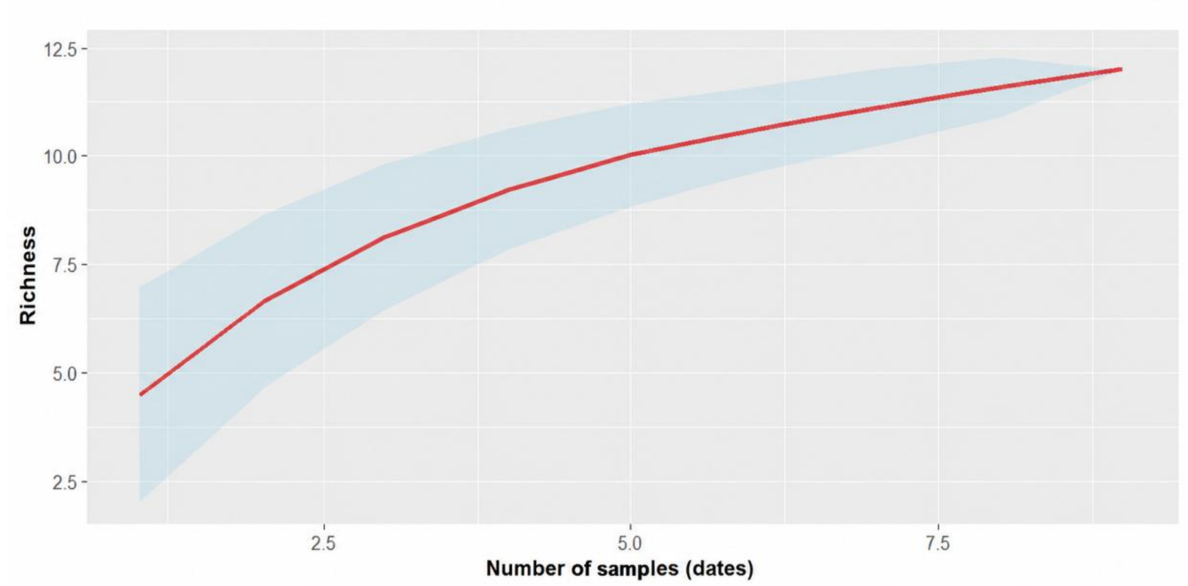

Figure 3. Genus accumulation curve of epigeic beetles sampled in the Kisangani Botanical and Zoological Garden. The red line indicates observed genus richness and the shaded area represents the confidence interval.

4. Temporal dynamics of beetle genera

Temporal patterns showed significant variation in beetle abundance across sampling dates, with total abundance peaking at the start of the survey (28 July) due primarily to high *Digitonthophagus* numbers (Figure 4). After this initial peak, *Digitonthophagus* abundance declined sharply and remained low for the rest of the period. *Onthophagus* was also relatively abundant at the beginning but maintained lower, stable levels thereafter. Most other genera were present only sporadically and in low numbers throughout the monitoring period. Most other genera persisted rarely throughout the monitoring period, generally at low abundances.

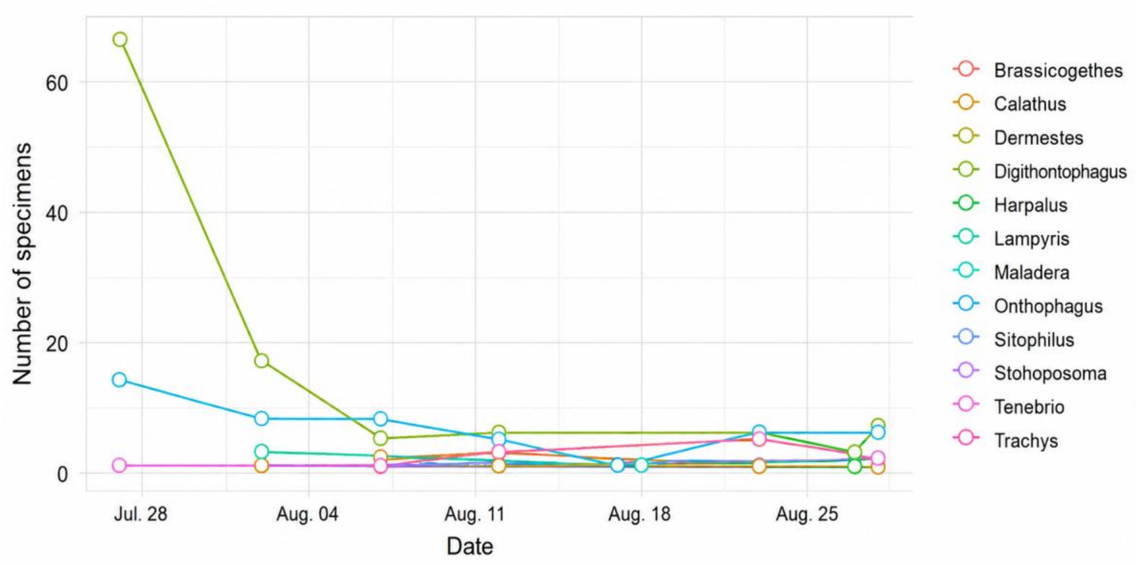

Figure 4. Temporal variation in the abundance of epigeic beetle genera during the sampling period. Lines represent the abundance of each genus across sampling dates.

Temporal dynamics of functional traits mirrored the overall abundance pattern, with the highest abundance on 28 July driven by the coprophagous guild. On subsequent dates, total abundance was lower, and while coprophagous beetles remained dominant, the relative contribution of other functional groups became more apparent as overall numbers declined. This indicates that temporal changes in the assemblage were primarily due to fluctuations in dominant dung beetle abundance, rather than balanced turnover among functional groups.

5. Temporal variation in richness and Shannon diversity

Taxonomic and functional diversity indices fluctuated throughout the sampling period, with both genus-level and functional-trait richness peaking in early August, declining sharply in mid-August, and partially recovering by the end of the survey. Shannon diversity followed a similar trend. Genus-level diversity was generally higher than functional-trait diversity, indicating that multiple genera shared similar functional roles within the coprophagous beetle-dominated assemblage.

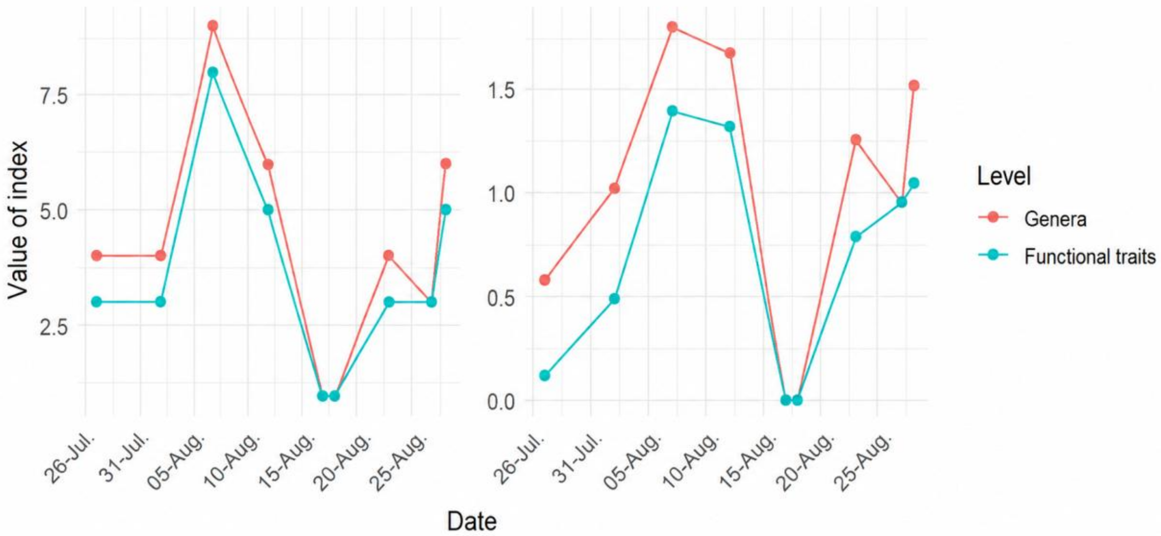

Figure 5. Temporal variation in genus richness and Shannon diversity of epigeic beetles during the sampling period.

IV. Discussion

The epigeic beetle assemblage in the Kisangani Botanical and Zoological Garden was taxonomically diverse but highly uneven, with 198 individuals from 12 genera and 10 families. Notably, two

Scarabaeidaegenera, **Digitonthophagus** and **Onthophagus**, accounted for 80% of total abundance, highlighting the garden's role as a resource-rich "island" for coprophagous beetles. The continuous supply of animal excreta from the zoological component provides a concentrated food resource, supporting dung beetle dominance and their key roles in dung removal, nutrient cycling, and soil functioning (deCastro‑ Arrazola *et al*., 2022). It is noteworthy that this dominance was observed despite the use of non-baited pitfall traps, whereas dung beetle studies commonly employ dung-baited traps. This pattern suggests that dung resources were sufficiently abundant within the zoological garden to influence beetle activity and local community structure without the need for experimental attractants. Nevertheless, because non-baited traps measure activity-density rather than direct attraction to dung resources, future studies should compare baited and non-baited trapping approaches to better quantify the strength of this resource-island effect. This suggests that urban zoological gardens can maintain important ecosystem-engineering functions even within fragmented urban landscapes. Although the dominance of *Digitonthophagus*and *Onthophagus* is consistent with increased use of dung resources, our data do not allow formal discrimination among Scarabaeinae behavioral guilds such as tunnelers, dwellers, and rollers. Consequently, the Resource Island hypothesis is evaluated here at the broader level of coprophagous dominance rather than specific dung-burying strategies.

The functional composition supports this interpretation, as coprophagous beetles were by far the dominant guild, while other groups, such as predators, detritivores, phytophagous beetles, necrophages, granivores, and pollen feeders, were much less abundant. This functional concentration, or narrowing, occurs when a single resource type dominates the environment, favoring specialized guilds and limiting the representation of other ecological functions (Doube, 1990). The observed dominance of dung-associated beetles suggests that resource concentration may influence community structure within the KBZG. However, because no reference forest fragments were sampled, it remains impossible to determine whether this pattern is unique to the zoological garden or reflects broader characteristics of urban forest remnants in the Kisangani landscape.Future studies should compare beetle assemblages among zoo-associated forests, urban forest fragments without large mammals, and less disturbed peri-urban forests to quantify the magnitude of any resource-island effect.(Cadotte *et al.*, 2011; Mammola *et al*., 2021).

An additional limitation is that beetles were identified only to the genus level. Although genus-level identification allows broad characterization of community composition and functional structure, several ecological traits, particularly trophic specialization and resource-use strategies within Scarabaeidae, may vary among species. Consequently, functional interpretations should be considered preliminary until species-level identifications become available.

The genus accumulation curve approached an asymptote after the eighth sample, indicating that the most common genera were captured during the study period. However, the slight upward trend at the end suggests that some rare genera may have been missed, which is plausible given the prevalence of rare or seasonally active taxa in tropical insect communities (Rafael *et al*., 2025; Novotný & Basset, 2000). Since insect activity in the Congo Basin is influenced by rainfall and temperature variability, extending the sampling period to cover both dry and wet phases would likely reveal additional temporal turnover (Ariza *et al*., 2021; Dijk *et al*., 2024; Yakusu *et al*., 2023).

Temporal patterns indicated community instability during the six-week survey, with abundance peaking at the start (mainly due to *Digitonthophagus*) and declining sharply thereafter. Functional abundance followed a similar trend, and temporal variation was driven by fluctuations in dominant coprophagous beetles rather than balanced replacement among functional groups. Richness and Shannon diversity were highest in early August, declined in mid-August, and partially recovered later. These fluctuations indicate short-term variation in community structure during the six-week survey period. However, because environmental variables such as rainfall, soil moisture, and temperature were not measured, the drivers of these temporal changes cannot be determined from the present study. Given the study's short duration, these patterns reflect short-term dynamics rather than seasonal trends. The six-week sampling period provides only a short-term snapshot of community structure and does not capture seasonal variation in beetle assemblages. Longer-term surveys covering both wet and dry seasons would be required to assess temporal turnover and seasonal dynamics more comprehensively. Such studies would help determine whether the dominance of coprophagous Scarabaeidae observed here is a persistent feature of the community or a temporary response to short-term environmental conditions and resource availability.

These results suggest that the Kisangani Botanical and Zoological Garden functions as a selective refuge rather than a comprehensive biodiversity refuge. The site appears particularly favorable to dung-associated Scarabaeidae, while other functional groups remain weakly represented. Consequently, the garden contributes to the maintenance of specific ecosystem functions, especially dung removal and nutrient cycling, but does not support a functionally balanced beetle assemblage. This highlights both the conservation value and ecological limitations of urban forest fragments, which maintain important soil-related ecosystem functions but may not preserve the full spectrum of functional diversity observed in less disturbed tropical forests (Eldridge et al., 2024; Hatfield et al., 2018).

V. Conclusion

We assessed the taxonomic and functional structure of epigeic beetles in the Kisangani Botanical and Zoological Garden and found a strong dominance of coprophagous Scarabaeidae, particularly *Digitonthophagus*and *Onthophagus*. This pattern is consistent with the hypothesis that concentrated dung resources influence community structure within the garden. However, the absence of reference sites, the short sampling duration, the lack of environmental measurements, and genus-level identification limit the strength of ecological inference. Rather than demonstrating a generalized refuge effect, our results suggest that the KBZG may function as a selective refuge for dung-associated beetles and the ecosystem functions they provide. Future studies incorporating species-level identification, direct environmental measurements, baited trapping, and comparisons with nearby non-zoo forest fragments will be necessary to determine the extent to which urban zoological gardens act as resource islands for dung beetles in Central African landscapes.

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